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2. Patent application number *(The Patent Office will fill in this part)*	0401082.3 19 JAN 2004
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	HOWES, Jonathan Sebastian 3 Chapel Cottages Cowfold Road Bolney West Sussex RH17 5QU G.B. MACNAGHTEN, James Fernleigh Cottage 3 Hill Avenue Cambridge CB1 7UY G.B.
Patents ADP number *(if you know it)*	832975001 (HOWES); 87788045001 (MACNAGHTEN)
If the applicant is a corporate body, give the country/state of its incorporation	
4. Title of the invention	IMPROVED KEEL
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	MAGUIRE BOSS 5 Crown Street St. Ives Cambridgeshire PE27 5EB, G.B.
Patents ADP number *(if you know it)*	07188725001
6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last six months	Country Priority application number *(if you know it)* Date of filing *(day/month/year)*
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Continuation sheets of this form	
Description	14
Claims(s)	
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Priority documents	
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TITLE: IMPROVED KEEL

DESCRIPTION

The present invention relates generally to a waterborne vessel having an improved keel, and particularly, but not exclusively, to a sailing vessel having an improved keel.

Fin keels (e.g. comprising a single fin supporting a ballast bulb) are well known in the art as a means of providing lateral stability to conventional sailing vessels. However, there are a number of problems associated with fin keels. For example, fin keels are structurally vulnerable to impacts and dynamic loads, with flexure of a fin keel having the potential to cause substantial damage thereto, particularly if cyclically applied loads (e.g. due to waves) are close to the natural frequency of the keel. Furthermore, efficient fin keels require a deep draught to ensure an adequate lifting efficiency. High aspect ratio fins suffer from a low

stalling angle which can lead to control problems in rough conditions, and in the worst cases can lead to regular loss of control of a vessel. In contrast, shorter (i.e. shallow draught) keels may be strong, but deliver poor upwind performance due to increased vortex drag.

A common solution to the problems relating to fin keels is to use a twin keel arrangement in which two shallow-draught fin keels are used instead one deep draft keel. Generally, the two keels are splayed outwards and provided with a small amount of "toe in" such that when a vessel is heeled, the leeward keel becomes more upright and is angled to best resist leeway. However, once in this orientation, the weather keel acts to increase heel, and both keels will produce substantial vortex drag. Although it is possible to design a hull for a twin keel arrangement such that the weather keel generates reduced force with increased heel, this is generally at the cost of hull performance. Furthermore, when sailing upright (e.g. downwind), both keels produce a counter-rotating vortex pair which also carries a significant drag penalty.

Another attempt at addressing some of the problems relating to fin keels is disclosed in GB 2177353 (Rennie), in which a keel is shown which comprises a pair of streamlined side foils depending (e.g. extending) symmetrically from lateral sides of a hull, the side foils converging to a junction below a centre-line of the hull to form an enclosed flow path for allowing water to pass through the keel. The purpose of this arrangement is

primarily concerned with the provision of a keel which is efficient in operation, namely by seeking to reduce induced drag experienced by the keel. Accordingly, the present applicants have identified the need for a sailing vessel having an improved keel which overcomes, or at least alleviates, some of the problems associated with conventional keel arrangements.

In accordance with the present invention there is provided a vessel for travelling on water, comprising a hull means and a keel comprising a member depending from the hull means, the member comprising two limbs each depending from a respective lateral side of the hull means, the two limbs defining at least in part an enclosed flow path extending in a bow to stern direction, the enclosed flow path being configured to allow water incident on the vessel to flow over inner and outer surfaces of the limbs, characterised in that the limbs each have a zero-lift surface which is angled to generate in use a component of hydrodynamic force directed away from the enclosed flow path.

In this way, a keel with an enclosed flow path (or "loop keel" defining a "loop") is provided which, when submerged in water in use, may result in a closed loop of hydrodynamic force, all directed away from (the centre of) the enclosed closed flow path. This situation is equivalent to a vortex ring in a continuous flow and, unless an overall lateral force is being generated on the loop keel, should not result in substantial vorticity being

shed by the loop keel.

In use, the angling of the zero-lift surface to generate an outward force may vary the degree by which the flow within the equivalent vortex ring is accelerated; this may manifest itself as an increase in the apparent inertia of the vessel (known in aerodynamics as the "added mass effect"). This inertia travels with the vortex ring and is experienced by the vessel as a significant increase in longitudinal and roll inertia, a small increase in yaw and pitch inertia, and some increase in heave and lateral inertia. This may have the effect of reducing the violence of the vessel's response to waves and other upsets.

In use, if the vessel should experience a significant heel angle such that part of one limb is partially clear of, and above the water surface, the other, lowest limb, by virtue of the angling of the zero-lift surface, generates a righting moment (assuming forward motion of the vessel is present). At lower angles of heel, the forces on the limbs of the loop will tend to force water to fill or partially fill the loop even when the loop is partially above the water surface. This manifestation of the added mass effect also now forms an additional dynamic ballast element in that the water within the loop that has been raised above the static waterline is now providing a weight-derived righting moment acting directly on the keel members. Any roll disturbance of the keel under forward motion may therefore generate a substantial righting moment.

At least one limb of the loop keel member may comprise a portion having a symmetrical aerofoil cross-section (for example, at least one limb may comprise a cross-section similar to a conventional fin keel), in which case, the portion will be aligned so that water will be incident on the inner surface of the limb so as to generate force away form the loop. In another form, at least one limb of the loop keel member may be cambered (for example, at least one limb may comprise an asymmetric foil section) to provide force generation away from the centre of the loop. In yet another form, the angle of the zero-lift surface of at least one limb may be variable. For example, at least one limb may be of variable camber (e.g. at least one limb may comprise a moveable flap) or a portion of at least one limb may be moveable (e.g. rotatable). For example, the loop keel may comprise a trailing- or leading-edge flap or both, or the loop keel may comprise one or more moveable limbs. In this way, the limbs may be angled so as to generate a continuous outward force all around the loop.

If the limbs of the keel are provided with a means to vary the angle of the zero-lift surface, e.g. by means of flaps or rotation of key parts of the limbs about their longitudinal axes, the apparent inertia of the entire vessel may be varied at will. This effect may be used to trade longitudinal momentum between the vessel and surrounding water with only minimal losses. This would allow a vessel so equipped to transiently slow down and speed up without any significant variation in power input.

One possible use may be for collision avoidance in racing situations where this could be used as a lossless brake. Furthermore, this effect may be of considerable use in the field of racing since, if a boat arrived at a start line for a race a couple of seconds early, some of the kinetic energy of the boat could be temporarily transferred to the water and then recovered after the starting gun had fired.

The two limbs may each comprise a substantially straight portion. For example, the member may comprise a pair of substantially straight limbs connected together to form a V-shape (when viewed from the bow or stern of the sailing vessel) with a portion of the hull means completing the loop to form the enclosed flow path. In another form, the two limbs may be substantially curved.

The two limbs may be symmetrically disposed on either side of a central, longitudinal axis of the hull means. The loop keel may be similarly symmetrical. The two limbs of the loop keel may be connected together direct or, for example, via a ballast bulb.

For improved hydrodynamic performance, the two limbs may be directed (e.g. curved) inwards toward the hull means where they depend from the hull means. For example, the two limbs may be substantially perpendicular to the hull means at the point where they meet the hull means, with the objective of minimising interference drag between the loop keel and the hull means, and to encourage the loop to break the water surface during significant heeling. It may also be desirable to locally increase the chord and reduce the

camber where the limbs meet the hull means to reduce the curvature experienced by the longitudinal flow at the waterline. In this way, wave drag may be reduced when the vessel is more or less upright.

The vessel may be a sailing vessel (i.e. intended to be propelled using at least one sail). However, the present invention is also applicable to non-sailing vessels (i.e. vessels not employing a sail, e.g. fishing vessels, survey craft or ferries); the inertia effects the vortex ring and dynamic righting moment that is generated by the loop keel may be of great use in such vessels. The righting moment generated by the loop keel will tend to maintain the hull in a substantially upright position in the water (e.g. force the vertical axis of the hull to remain substantially normal to the water surface) as long as the vessel is in forward motion, and has clear benefits in terms of ride comfort and seaworthiness for any vessel.

The hull means may be a monohull or, alternatively, the hull means may comprise a multi-hull arrangement, provided that there is a hydrodynamic surface to form the loop.

The keel may further comprise a ballast portion. For example, the loop keel may comprise a ballast bulb disposed at a lowest part of the keel (e.g. at the apex of a V-shaped loop keel). Alternatively, or in addition, the loop keel may further comprise a substantially planar, horizontal element disposed at a lowest part of the loop keel member, and containing ballast. The substantially

planar surface may be configured to support the sailing vessel when grounded, e.g. between tides. At the base of the loop keel, the two limbs may be angled (e.g. curved) to smoothly meet the ballast bulb. However, many of the advantages of the present invention are also applicable for an unballasted keel.

An embodiment of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a schematic perspective view of an underside of a sailing vessel embodying the present invention;

Figure 2 shows a force diagram representing the vortex ring produced by the loop keel of the sailing vessel shown in Figure 1;

Figure 3 shows a split schematic front/rear view of the sailing vessel of Figure 1;

Figure 4A shows a schematic side view of the sailing vessel of Figure 1;

Figure 4B shows a schematic plan view of one half of the sailing vessel of Figure 1;

Figure 5 shows the sailing vessel of Figure 1 compared with a conventional fin keel sailing vessel in a heeling position;

Figure 6 shows a schematic representation of the sailing vessel of Figure 1 and the convention single heel sailing vessel of Figure 5 in a cross-flow;

Figure 7A shows a graph illustrating the concept of

the zero lift surface;

Figure 7B shows a cross-sectional diagram of a cambered aerofoil; and

Figure 7C shows a cross-sectional diagram of an uncambered aerofoil.

Figures 1, 3, 4A and 4B show a sailing vessel 10 comprising a hull 20 and a loop keel 30, the loop keel 30 comprising a substantially V-shaped looped keel member 34 attached to the hull 20 at two laterally spaced locations 38,39. The looped keel member 34 comprises a pair of limbs 44, each having substantially straight fin-like portions 45 which are attached at one end to a central ballast bulb 42, and curved, upper portions 46 which attach the loop keel to the hull 20 at the two laterally spaced locations 38,39. The pair of limbs 44 in combination with the hull 20, form an enclosed flow path (a "loop" or aperture) 40 through which water may pass.

The limbs 44 comprise inner and outer surfaces (44a,44b) which are configured so as to generate a continuous outwards force all around the loop (this is directly equivalent to a vortex ring in a continuous flow). For example, fin-like portions 45 may have a cambered or uncambered foil profile having a zero lift surface which is angled to generate a component of hydrodynamic force directed away from the enclosed flow path 40 when the loop keel 30 passes through incident water. Additionally, the pair of limbs 44 may include one or more moveable flap (not shown) to control apparent

inertia of the sailing vessel 10. Figure 2 shows schematically the equivalent vortex ring produced by the loop keel 30 when zero overall lateral force is applied thereto.

Figure 5 shows various forces acting on the sailing vessel 10 in a heeled position as compared with the forces acting on a conventional sailing vessel 50 comprising a fin keel 52. Whereas all the dynamic forces shown acting on the fin keel 52 act to increase the heeling moment, all of the dynamic forces shown acting on the loop keel 30 act to reduce the heeling moment. The ballast effect for both keels is similar.

Figure 6 shows the conventional fin keel 52 and the loop keel 30 in a cross flow. With a conventional fin keel, any cross-flow results in a sudden increase in incidence. In contrast, cross-flow results in a component of flow along the limbs 44. When coupled with fore and aft flow, this acts to reduce the local incidence change, and thereby provides improved stall resistance. The advantages of the present invention may be explained as follows. When the rig of the sailing vessel is loaded, the effect is to both load the loop keel laterally to resist the rig load and to generate a heeling moment to leeward. The effect of this on the loop keel is to cause the weather limb of the loop keel to become more upright and also, depending on the particular design, to break the water surface and thus disturb the equivalent vortex ring of the unloaded keel. As this limb is angled to generate force

away from the centre of the loop, it is ideally placed to generate an efficient leeway resisting force, this force is also generated without requiring the hull to crab as with a conventional fixed fin and this can be used to reduce the heeled hull drag. It also has a further advantage over a fin keel in this condition, since the other limb of the keel (the leeward limb) still provides surface continuity and acts in the same manner as an aircraft winglet increasing the effective aspect ratio of the keel and thus reducing the vortex drag. The leeward limb generates a force both downward and to a lesser degree to leeward. The hull, due to the heeling angle, also moves the centre of buoyancy to leeward (form stability) and the force from the leeward keel limb is offset from the centre of buoyancy to weather, this results in a dynamic righting moment. The overall result is that a loop keel equipped yacht should sail to windward with less drag and less heel than a similar yacht equipped with a fin keel.

Yet a further advantage of the loop keel is that the limbs of the keel will always offer some element of the working keel surface to the water flow at a lateral angle, which will tend to cause a degree of cross flow which has the effect of increasing resistance to stalling. The keel will thus generate lift to high angles of attack and be highly resistant to stall in rough conditions. The loop keel is also of a naturally sturdy and stiff structural form and is very unlikely to suffer from elastically induced dynamic overloads.

If two otherwise similar sailing vessels are equipped with a fin keel and a competing loop keel of similar draught, the loop keeled vessel will sail downwind with a similar performance to the fin-keeled vessel. However, as soon as the course is such as to place a lateral load on the keel, the loop keeled vessel will sail faster, with less heel and thus a correspondingly more efficient rig, and will be more controllably in extreme conditions. It will also be significantly stronger. If the performance of the two vessels is matched, the loop keeled vessel will have a lower draught than the fin keeled vessel; this reduction in draught is likely to be of the order of 20% to 30%.

ANNEX

The graph of Figure 7A illustrates the concept of the zero lift surface for a cambered (i.e. asymmetric) aerofoil and an uncambered (symmetrical) aerofoil, as illustrated in Figures 7B and 7C respectively. The graph shows a plot of the lift coefficient (CL) versus the incidence in degrees for both the aerofoils.

The cross-section of the cambered aerofoil has two lines superimposed on it, one of which is the geometric datum of the foil section (i.e., the line about which the aerofoil co-ordinates are defined for plotting purposes), the other of which represents the zero lift line for this aerofoil. It should be noted that the zero lift line relates to a 2 dimensional aerofoil section. When this is related to a real foil surface the zero lift lines of every local aerofoil section merge together to form the zero lift surface. This may be planar but in the case of a non-planar foil this need not be the case.

As shown, at an angle of incidence of zero degrees, the cambered aerofoil will generate positive lift. However, at an angle of approximately minus two degrees the lift generated is zero. This means that to generate zero lift the cambered aerofoil must be set at an angle to the flow of about minus two degrees and this flow datum is shown on the cross-section of the chambered aerofoil as the zero lift line.

The lift slope for the uncambered aerofoil is also shown on the graph. In contrast to the cambered aerofoil,

this arrangement produces zero lift at an incidence of zero degrees. In this case, and for any symmetrical section or form including flat plates and bluff bodies, the zero lift line coincides with the axis of symmetry of the body or foil.

The lift gradient with incidence of both the symmetrical and cambered forms is similar. The corollary of this is that over the approximately linear range of foil behaviour the lift is directly proportional to the incidence of the zero lift line relative to the undisturbed fluid flow axis (i.e., the flow axis of the fluid in the absence of the foil).

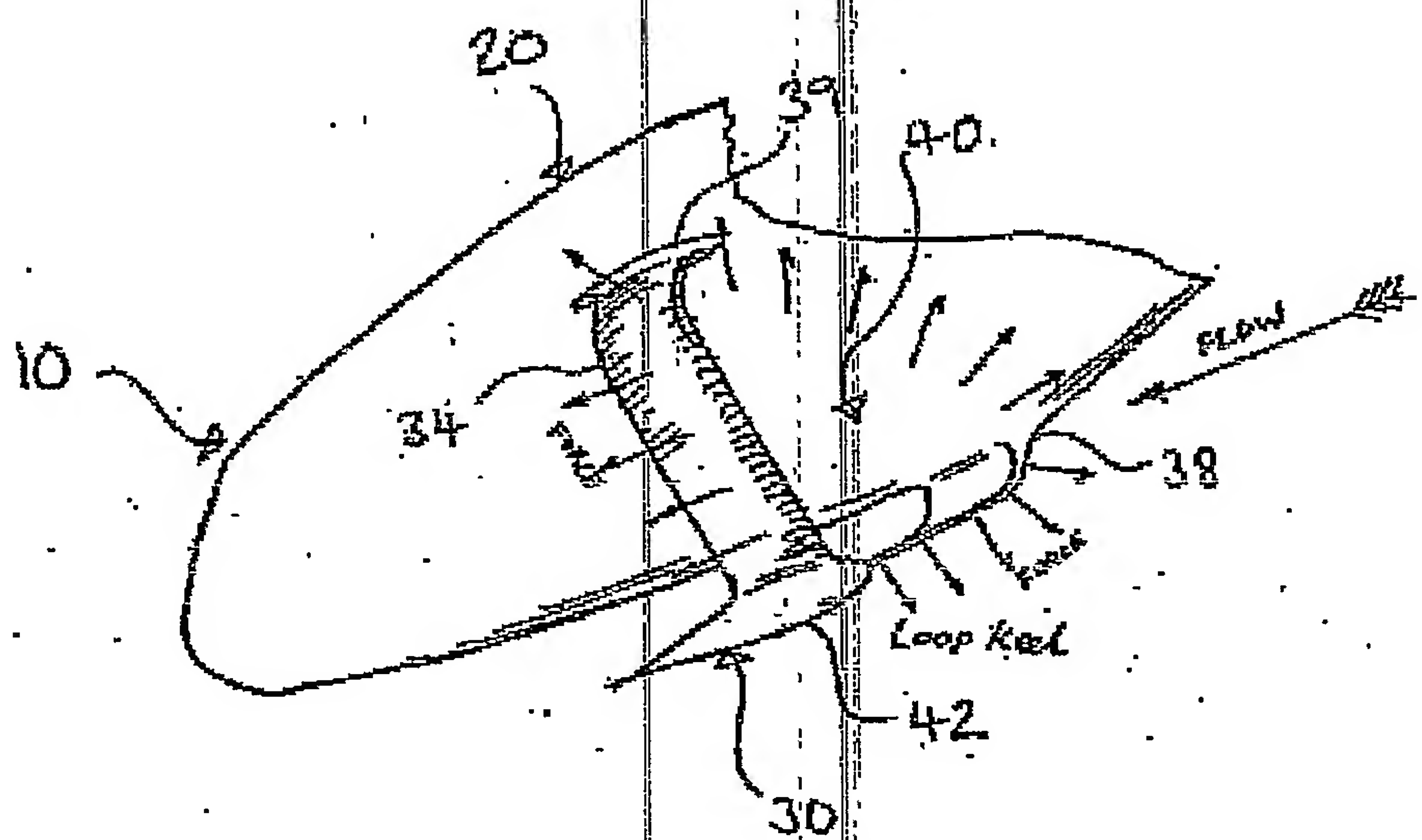


FIGURE 1

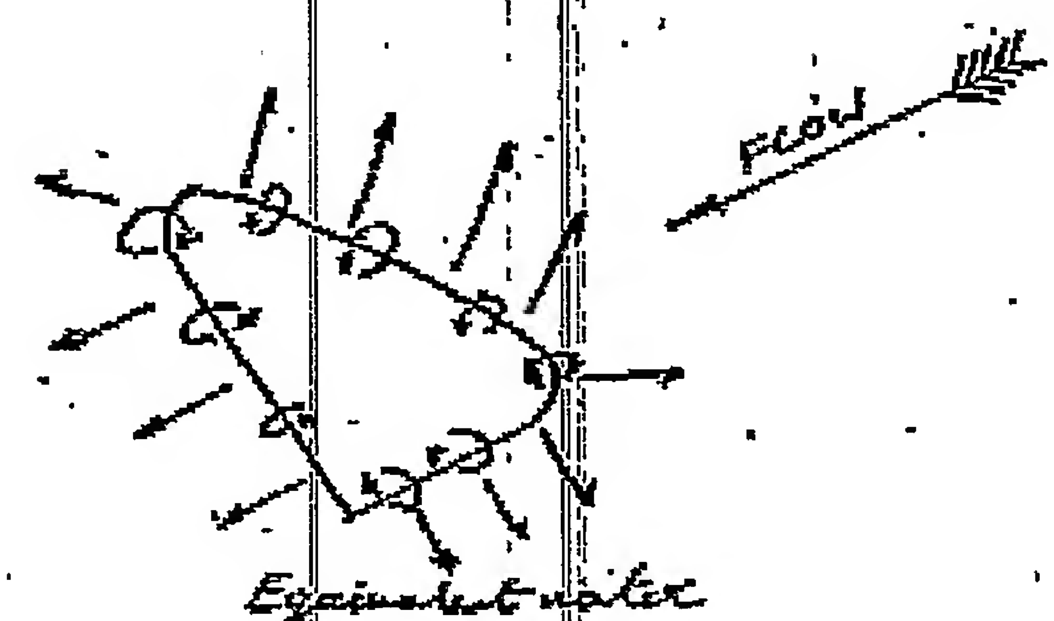


FIGURE 2

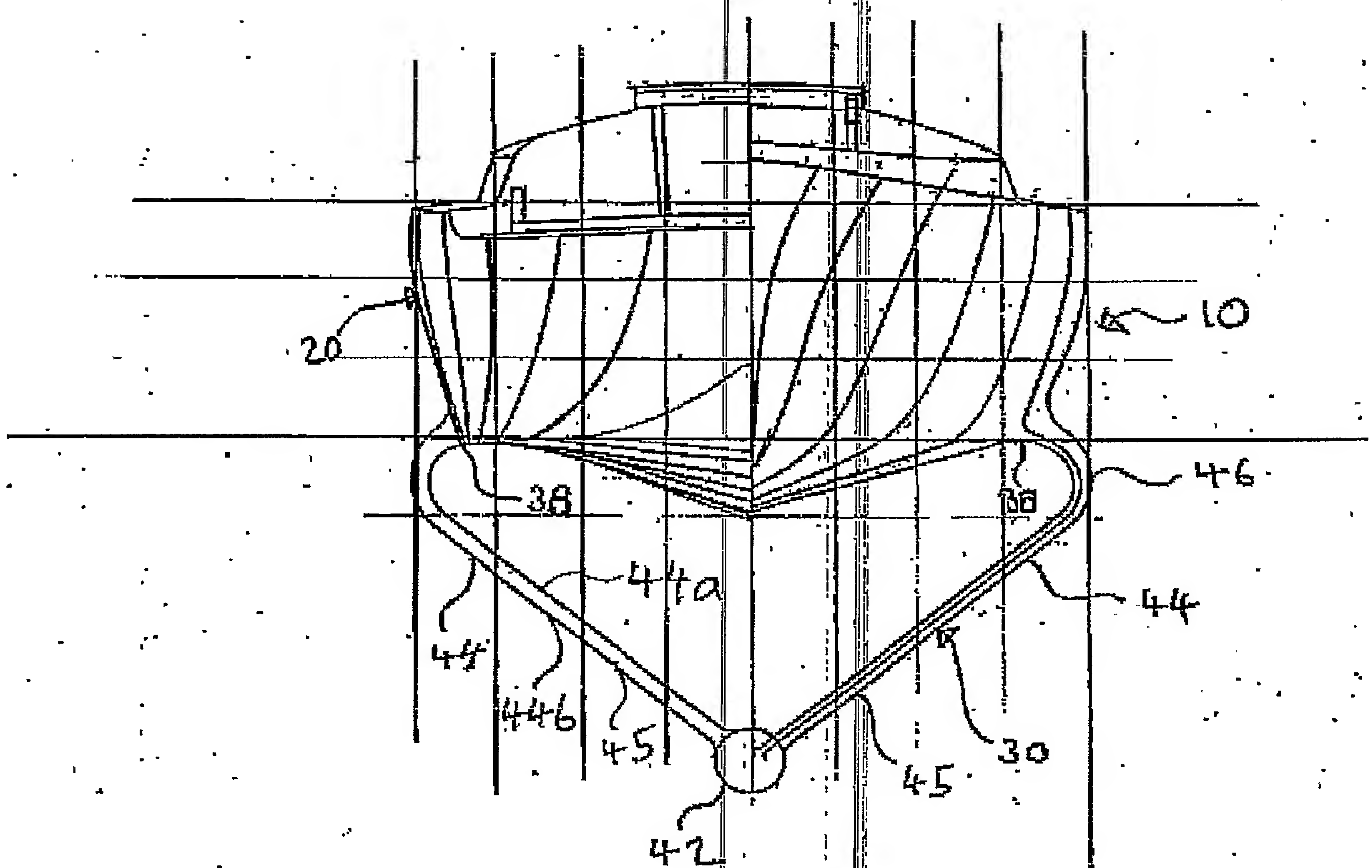


FIGURE 3

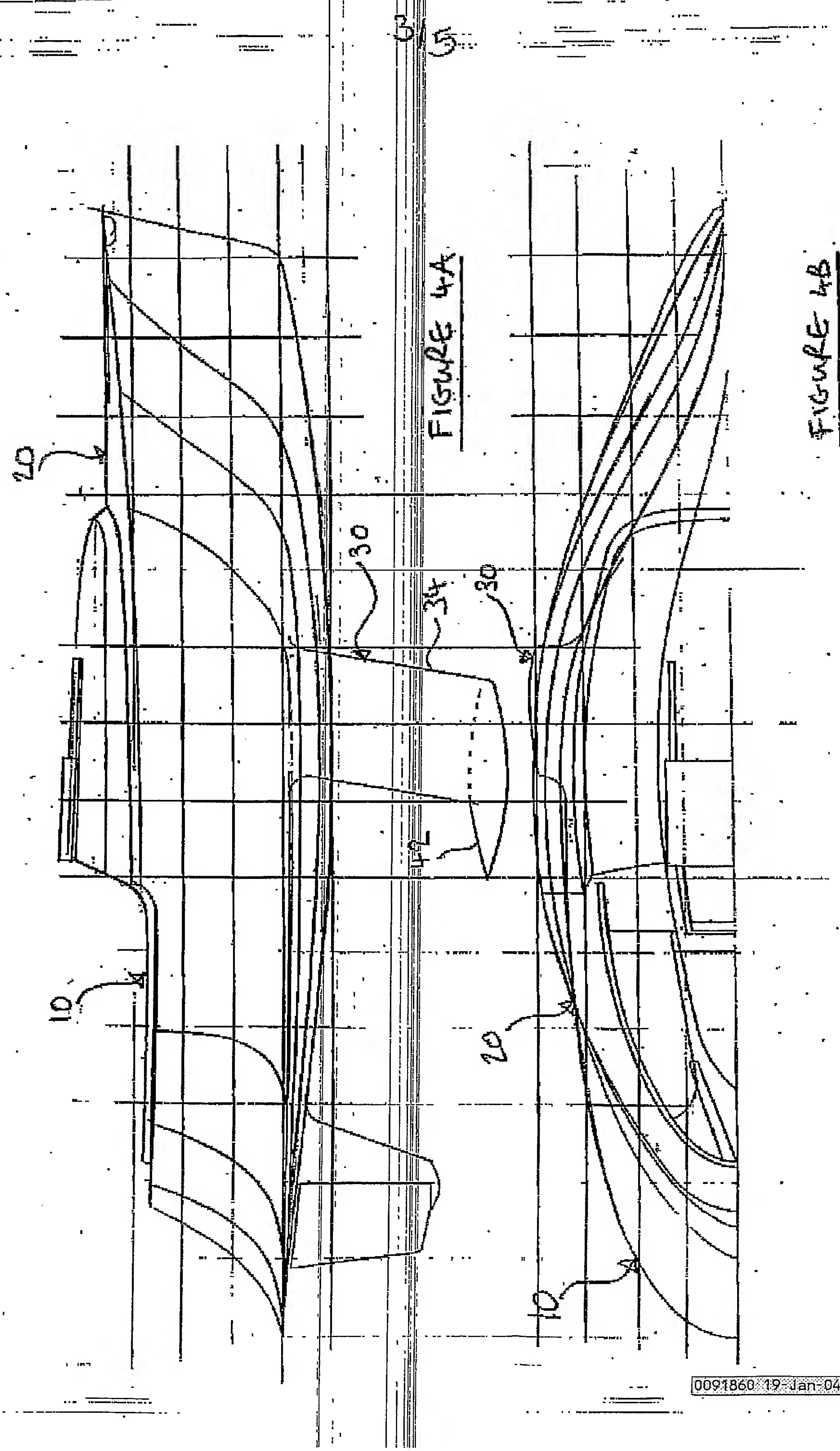


FIGURE 4A

FIGURE 4B

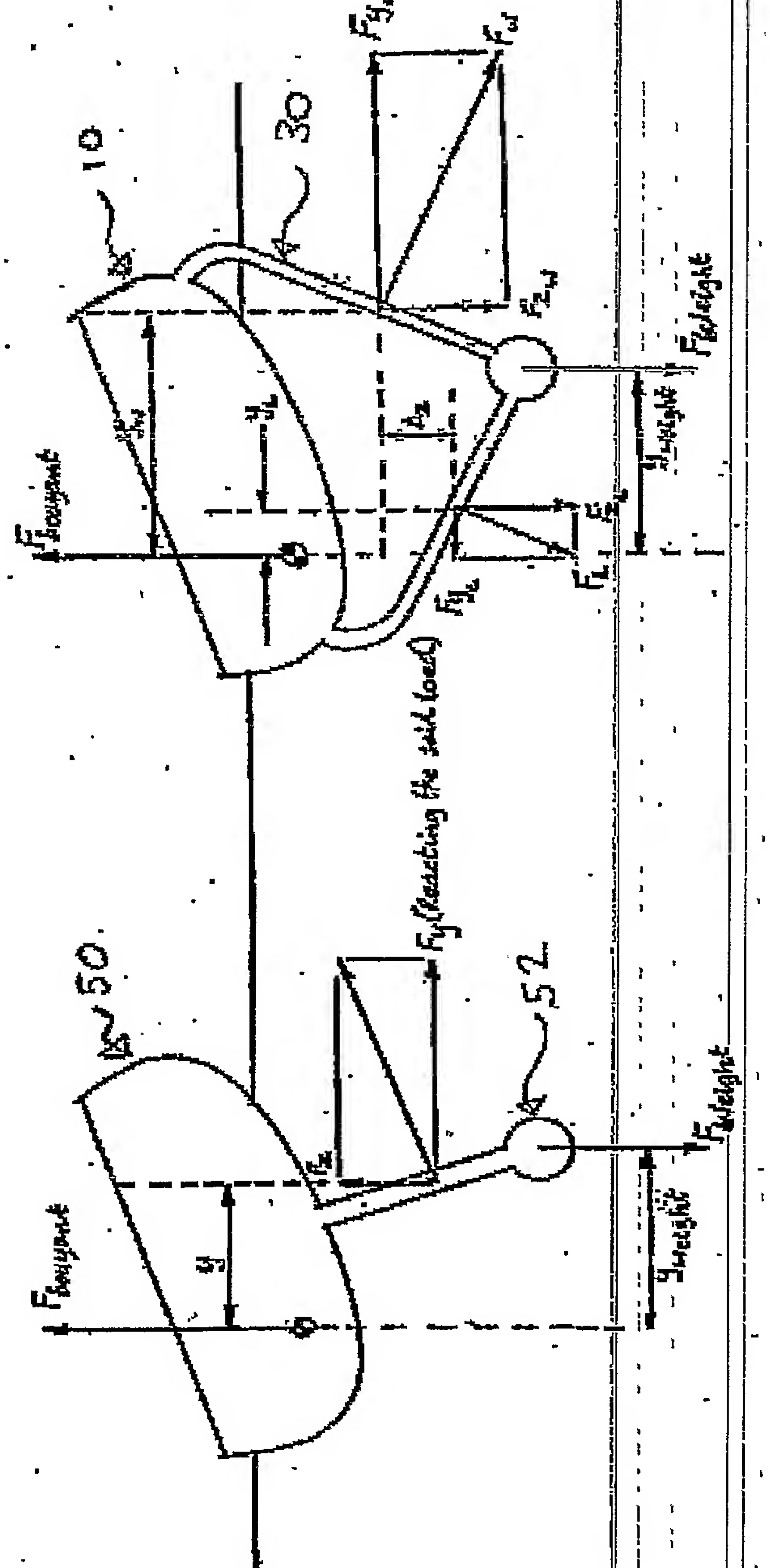


FIGURE 5

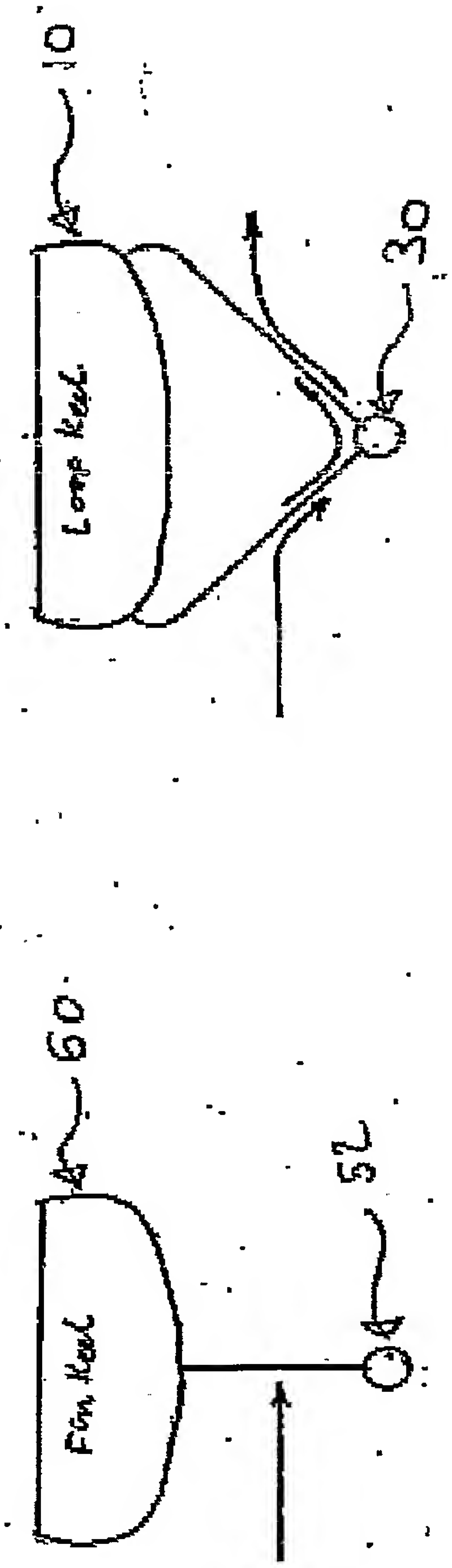


FIGURE 6

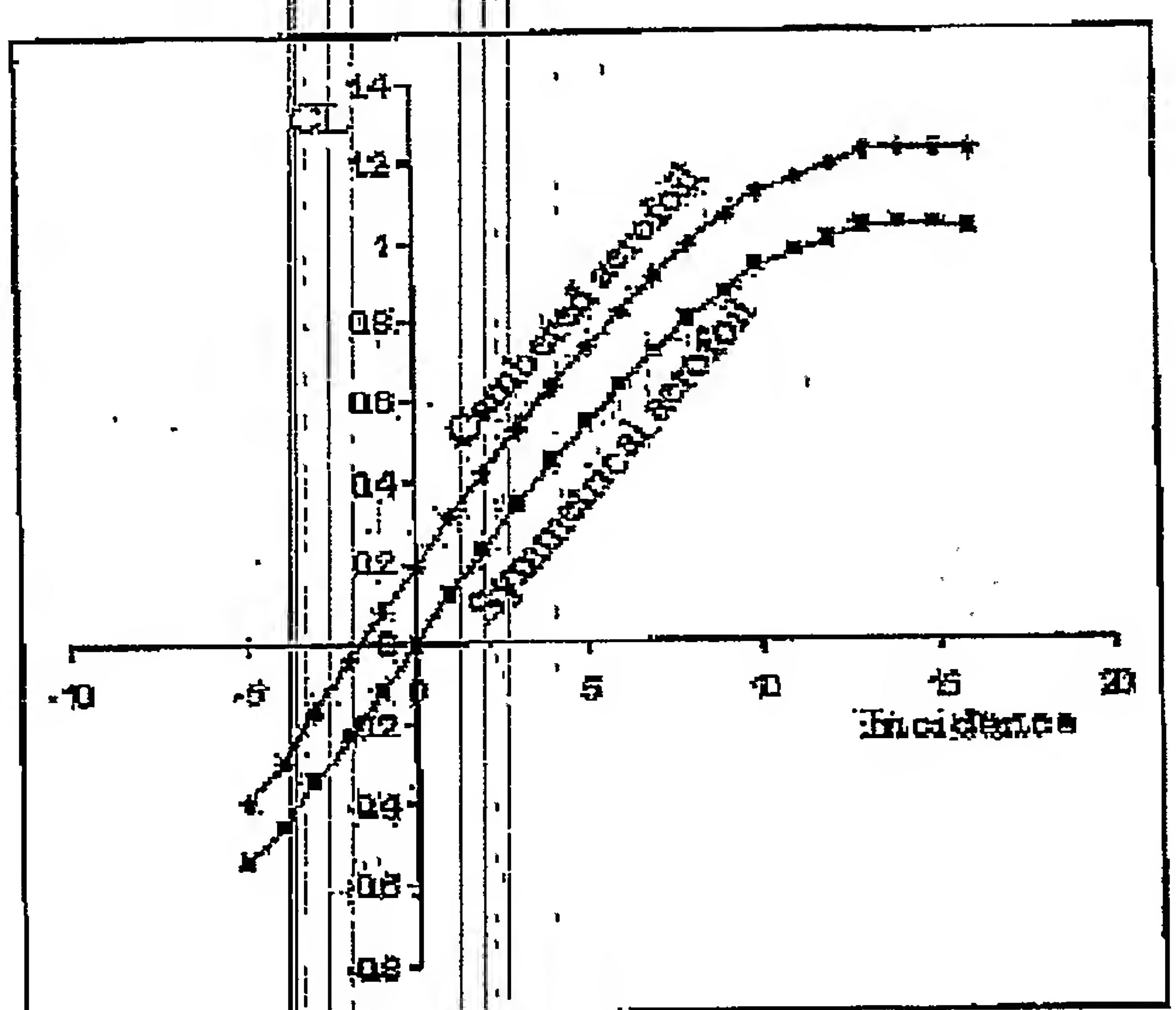
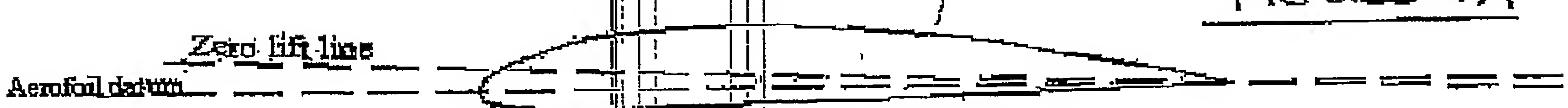


FIGURE 7A



Cambered aerofoil (Clark Y Section)

FIGURE 7B

Symmetrical aerofoil (NACA0010 Section)

FIGURE 7C